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# Muscle Activity During Aquatic and Land Exercises in People With and Without Low Back Pain

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**Background.** Chronic low back pain (CLBP) is the most prevalent musculoskeletal disorder. Aquatic exercises are commonly used by physical therapists for CLBP treatment and management; however, there are no data on trunk muscle activation during aquatic exercises in people with CLBP.

**Objective.** We quantified activation of trunk and gluteal muscles, exercise intensity, pain, and perceived exertion in people with and without CLBP when performing water and land exercises.

**Design.** The study used a cross-sectional design.

**Methods.** Twenty participants with nonspecific CLBP and 20 healthy participants performed 15 aquatic exercises and 15 similar land exercises. Mean and peak muscle activation were measured bilaterally from erector spinae, multifidus, gluteus maximus, gluteus medius, rectus abdominis, external oblique, and internal oblique using waterproof and wireless surface electromyography. Exercise intensity (heart rate), perceived exertion (Borg scale), and, for the CLBP group, pain (visual analog scale) were recorded.

**Results.** There were no significant between-group differences. Significant between-environment differences were found in heart rate (always higher on land), exertion (higher in the water for 3 exercises and on land for 6 exercises), and muscle activation (higher on land in 29% and in the water in 5% of comparisons). Pain levels were low, but pain was reported more than twice as frequently on land than in water (7.7% vs 3.7%, respectively).

**Limitations.** People with high levels of disability and CLBP classification were not included.

**Conclusions.** People with mild-to-moderate CLBP had similar exercise responses to healthy controls. Aquatic exercise produced sufficient muscle activation, intensity, and exertion, and should not be assumed to be less strenuous or less effective in activating trunk and pelvic muscles than exercise on land. These data can be used to inform design and prescription of rehabilitation programs and interventions.

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Low back pain (LBP) is the most prevalent musculoskeletal disorder, affecting nearly everyone at some point during their lifetime and 4% to 33% of the population at any given time.[1,2] LBP has a major impact on quality of life and is also a cause of disability and absence from work. For example, about 150 million working days are lost annually in the United States because of back pain,[3] whereas in the United Kingdom over 200,000 people report back pain at work at least once every year.[4] LBP has also a very high economic cost, with the annual cost in the United States, for instance, estimated at $100 billion to $200 billion.[5] The majority (85%) of LBP cases are described as "nonspecific" due to a mismatch between symptoms and radiological findings.[6] Recurrence and chronicity are common, with less than 40% of patients being pain-free 12 months after an acute LBP episode.[7]

Exercise therapy on land targeting spinal and trunk musculature commonly forms the foundation of clinical programs for people with chronic LBP (CLBP) and has been shown to reduce pain and disability and improve muscle function and strength.[8,9] Approaches in exercise programs include generalized graded exercise and exercises that target the recruitment of specific muscles to improve lumbopelvic stability, because altered neuromotor control of the spine and pelvis[10] and generalized weakness around the hip and abdominal muscles have been identified in this population.[11] Aquatic exercise is also often used in the management and treatment of LBP because it has some important benefits compared with land exercise and can assist with balance, mobility, and pain control. For example, warm water can facilitate muscle relaxation,[12] buoyancy reduces joint loads,[11] and hydrostatic pressure provides support.[1] Studies on aquatic exercise have reported positive effects on patient outcomes, such as improved function and muscular endurance, increased spinal flexibility, and reduced absence from work.[13–18]

With the positive effects of exercise well documented,[19] leading bodies, such as the UK's National Institute of Health and Care Excellence, recommend exercise in all its forms for people with LBP.[20] However, it is not yet known which form of exercise could be superior for the management or treatment of LBP.[21] Aquatic exercise has been reported to have similar[14,18] or greater improvements[1,13,16,17] than land programs and might be more appropriate for people with LBP, in particular for the initial stages of rehabilitation and for those who have difficulties performing land exercises.[22]

Nevertheless, despite the evidence on aquatic exercise usefulness for people with LBP, practical application of research findings in this area is still limited. One reason is that the programs and exercises used in aquatic studies are typically not well reported or not reported at all.[1] Moreover, to maximize program effectiveness and specificity, it is vital that exercises target directly the muscles of interest. However, due to the complexities of electromyography (EMG) measurements in the water, knowledge of trunk muscle activation during aquatic rehabilitation exercises is very limited. The most commonly tested exercises are underwater walking or deep-water running,[23,24] with just a few studies investigating a small number of rehabilitation exercises.[22,25] Furthermore, EMG studies have typically used electrodes on 1 side of the body directly linked by cables to external receivers. Such systems cause active drag, affect exercise execution, and inhibit movement disproportionally between left and right. They also provide only unilateral information on muscle activity, a potentially important limitation, particularly for asymmetrical exercises.[26] Finally, to our knowledge, no aquatic studies have measured trunk muscle activity in people with CLBP. With studies on land reporting maladaptations of the neuromuscular system of the spine for people with CLBP[27] and also differences in muscle activation between people with and without CLBP,[10] EMG data during aquatic exercises are required for people with CLBP.

Considering the above limitations, exercise selection by physical therapists is often arbitrary or based on anecdotal evidence. Further research in this area with improved methods is therefore needed to advance knowledge and facilitate generalizability of findings. This would provide an evidence base to inform clinical practice and exercise prescription, which could then lead to improved quality, efficiency, and effectiveness of exercise interventions and rehabilitation. Thus, the aim of this study was to investigate trunk and gluteal muscle activation, pain, intensity, and perceived exertion during aquatic and land exercises in people with and without CLBP.

## Methods

See supplementary material online (available at https://academic.oup.com/ptj) for full methodological details on inclusion/exclusion criteria, exercise selection process and rationale, identification of repetition onset, participant familiarization, and EMG normalization and processing.

### Participants

Power calculations using GPower 3.1 showed that for a power of 80% to detect a medium effect ($f = 0.25$, $\alpha$-level = .05), a total sample of 34 participants would be required.[28] Therefore, 40 men volunteered for this study, 20 with nonspecific CLBP of more than 12 weeks' duration (mean [standard deviation, SD] values: age = 33.1[6.3] years; height = 1.81[0.07] m; weight = 82.6[23.4] kg; body mass index [BMI] = 23.6[1.9] kg/m$^2$) and 20 without musculoskeletal disorders but similar group characteristics to those of the CLBP group (age = 28.5[7.8] years; height =1.78[0.07] m; weight = 77.5[8.5] kg; BMI = 24.4[2.3]). The CLBP group mean (SD) values for the Oswestry Disability Index questionnaire, the TAMPA scale for kinesiophobia, and the STarT back screening (total and subscore) were, respectively, 21.1(11.5)%, 32.5(6.0), 1.5(1.2), and 0.7(0.7). Ethical approval was obtained from the institutional ethics committee. All participants read the participant information sheet and signed an informed consent form before commencing the study.

### Exercise Selection Process and Rationale

Exercises were selected based on appropriateness for rehabilitation, following a thorough multistage process that included open consultation with physical therapists and beneficiaries. Body movements, instructions to participants, and cadence were standardized. The 14 exercises with upper extremity dynamic movements and 16 exercises with lower extremity dynamic movements used in this study are described in Figure 1. Exercises will be referred to according to their numbering in Figure 1 (eg, Ex1L, Ex1R, Ex2, etc).

The land and water environments have some fundamental differences; eg, buoyancy acts in the opposite direction to gravity, and water resistance is extremely difficult to replicate on land. Therefore, when selecting land exercises, the intention was not to create identical conditions between the 2 environments—something that would probably be impossible. Instead, by selecting commonly used land rehabilitation exercises that have very similar movement patterns to those in the water, the aim was to provide comparisons that would be particularly useful for professional practice and would further inform rehabilitation program prescription for both environments.

### Experimental Setup

Aquatic testing took place in a 25-m indoor pool (depth = 1.25 m, average water temperature = 28°C). For EMG measurements, a 16-channel Mini-Wave Waterproof EMG system (Cometa SRL, Milan, Italy) was used. This system was wireless and waterproof, substantially reducing active drag and movement inhibition compared with systems with external cables connecting electrodes to amplifiers. Standard Ag-AgCl electrodes (Ambu Blue Sensor Electrode, Ambu Ltd, St Ives, UK) were placed on the skin on the left and right sides of the body over the muscles erector spinae (ES), multifidus (M), rectus abdominis (RA), external oblique (OE), internal oblique (OI), gluteus maximus (GMax), and gluteus medius (GMed) using SENIAM guidelines[29] for spinal extensors and gluteal muscles and, in the absence of SENIAM guidelines, recommendations by Boccia and Rainoldi[30] and Huebner et al[31] for abdominal muscles. EMG data were sampled at 2000 Hz. Aquatic exercises were recorded by 2 underwater and 2 above-water cameras (ELMO PTC-400c, Promotivations Visual Technology, Nuneaton, UK, 25 Hz, synchronized and genlocked). Land exercises were recorded through a 9-camera motion capture system (100 Hz; Qualisys Inc., Gothenburg, Sweden). These recordings were used to identify the onset of each repetition for subsequent EMG processing.

### Data Collection

Participants undertook familiarization for the water and land exercises in separate sessions and on different days to those of the experimental data collection. On testing days, each participant performed a 5-minute warm-up on a Monarch-814 bike (Monark Exercise AB, Vansbro, Sweden; power output 30 W at 60 rpm), followed by 12 to 15 repetitions of the exercises subsequently used for the submaximal contractions at a self-selected comfortable intensity. The EMG electrodes were then applied and land-based submaximal isometric contractions performed for EMG data normalization. Maximum voluntary isometric contractions (MViC) were not used to normalize EMG data due to the limitations of obtaining MViC data in a LBP population.[32] For the main data collection, exercise order was randomized and data were collected for 10 repetitions per exercise. The mean and peak EMG values were calculated for repetitions 2 to 9. At the end of each exercise, the rate of perceived exertion (RPE; Borg scale, scored from 6 to 20), the intensity of exercise (heart rate [HR], beats per minute; Polar Monitor, Kempele, Finland), and, for the CLBP group, pain (visual analog scale, scored from 0 to 10) were also recorded.

### Statistical Analysis

Data normality and homogeneity of variance were checked through Shapiro-Wilk and Levene tests ($\alpha$ = .05). For each exercise, EMG comparisons between the CLBP and control groups, and between the water and land environments, were made using 2-way analysis of variance with 1 between-factor and 1 within-factor (group $\times$ environment). Bootstrapping for non-normal data was carried out using $t$ tests in the post hoc investigation of main effects of group or environment. Because of the volume of comparisons, the post hoc $\alpha$-level was set at .01 to mitigate for the experiment-wise error rate. Post hoc analyses were not carried out for the interactions because the analysis of variance showed no significant differences. Effect sizes were calculated using partial eta squared[33] ($\eta^2$), with small, medium, and large effects classified as values of 0.0099, 0.0588, and 0.1379. Differences between CLBP and control groups for HR and RPE were carried out separately in water and land environments using independent $t$ tests ($\alpha$ = .05). Pain data for land and water exercises were compared using nonparametric methods (Wilcoxon matched-pairs signed-rank tests; $\alpha$ = .05) due to skewed distributions resulting from the many zero scores obtained.

### Role of the Funding Source

The present study was funded by the Chief Scientist Office in Scotland, project reference number ETM/378. The funding source had no role in the study's design, conduct, and reporting.

## Results

Examples of EMG data recorded during the exercises are shown in Figures 2 and 3. Figure 2 illustrates the mean

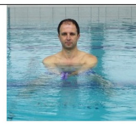
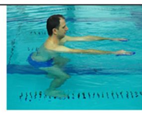
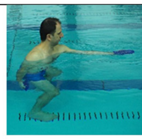
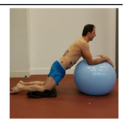
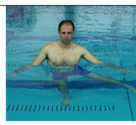
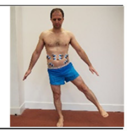
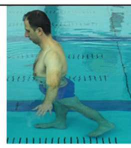
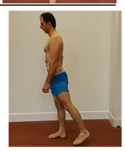
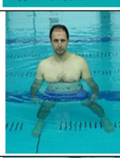
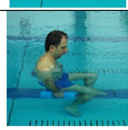
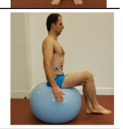
| Aquatic Exercises | | Land Exercises | |
|---|---|---|---|
| **Description** | **Photo** | **Description** | **Photo** |
| 1L and 1R (performed separately): Hold a disc (23cm diameter) between the hands just below water surface with arms fully outstretched in front. Rotate the trunk steadily as far to one side as possible and back to midline (35 bpm). |  | 1L and 1R (performed separately): Hold a Swiss ball (55cm diameter) between the hands with arms fully outstretched in front at chest height. Move the ball steadily as far to one side as possible and back to midline (35 bpm). |  |
| 2: Hold a kicking board (34x24cm) vertically with arms fully outstretched just below water surface. Move the arms backwards towards the body and forwards to the starting position (45 bpm). |  | 2: Hold a Swiss ball (55cm diameter) with arms fully outstretched in front at chest height. Bring it close the chest and then return to starting position (45 bpm). |  |
| 3: Hold buoyant discs (12.5cm diameter) in each arm just below water surface, the left close to the body and the right fully outstretched. Perform alternate reciprocal punching actions with the arms (45 bpm). |  | 3: Hold a blue Theraband in each hand passing round the trunk level at the middle of the thoracic spine. Alternately fully outstretch the arms, similar to a punching action (45 bpm). |  |
| 4: Have arms by the sides with forearms pronated and paddles (12.5x20cm) strapped to the hands. Bring the arms together to just below water surface while flexing the knees to a squat. Return to starting position (45bpm). |  | 4: Hold a Swiss ball (55cm diameter) above the head with arms fully extended. Move the ball to chest height while performing a squat with the lower body. Return to starting position. (45 bpm). |  |
| 5: Have the left arm by the side and the right arm outstretched in front, just below the surface, with forearms supinated and paddles strapped to the hands. Bring the left arm to just below water surface and simultaneously the right arm to the side. Return to starting position (30 bpm). |  | 5: Have the arms by the side of the body and hold the two ends of a blue Theraband passing behind the body under the gluteal fold. Move alternately each arm upwards to chest height and back to starting position (30 bpm). |  |
| 6: Have the trunk in an upright position, arms outstretched and hands resting on the surface holding dumbbell floats. Move dumbbells forwards slowly with the body in a neutral posture tilting on the tips of the toes. Return to starting position maintaining neutral body posture (12bpm). |  | 6: Kneel on the ground in an upright posture with hands resting on a Swiss ball (65cm diameter). Roll the ball forwards slowly until forearms are resting on it and shoulders are above elbows. Roll back to starting position maintaining a neutral body posture (20 bpm). |  |
| 7L and 7R (performed separately): Stand on one leg with arms abducted at 45º. Abduct the opposite leg as far as possible, retaining a neutral position throughout (avoid external rotation). Return to starting position (45bpm). |  | 7L and 7R (performed separately): Same as aquatic exercises 7L and 7R. |  |
| 8L and 8R (performed separately): Stand on one leg with arms abducted at 45º. Perform hip extension maintaining the lower limb in a neutral position (avoid external hip rotation). Return to starting position (45bpm). |  | 8L and 8R (performed separately): Same as aquatic exercises 8L and 8R. |  |
| 9L and 9R (performed separately): Stand on one leg with arms crossed at chest, the non-weight bearing limb in a neutral position with the knee flexed to 90º. Perform single leg squat on the weight-bearing limb so that the knee moves just in front of the toes (50bpm). |  | 9L and 9R (performed separately): Same as aquatic exercises 9L and 9R, but with arms by the side. |  |
| 10: Stand on both legs with arms by the side. Take a large step to one side keeping the knee extended, then bring the other leg next to it. Repeat to the other side (65bpm). |  | 10: Same as aquatic exercise 10, but with a blue Theraband tied round the ankles (40bpm). |  |
| 11: Hold dumbbell floats in each hand and position the arms by the side. Raise the knees alternately until thighs are parallel to the water surface (30bpm). |  | 11: Sit on a Swiss ball (65cm diameter) with knees positioned at 90º and arms by the side without the hands touching the ball. Raise the feet alternately from the ground to a height of approximately 20cm (30bpm). |  |

**Figure 1.**
Description of the aquatic and land exercises used in the present study. For Exercises 1–5 (Ex 1–5), participants had the same starting position for water and land, with feet a shoulder-width apart and knees in slight flexion (15–30°). This lower limb position with a static pelvic posture was maintained throughout the exercises (except Ex4 where the static foot position only was maintained). For Ex 7–11, the participants were instructed not to move their trunk. bpm = beats per minute.

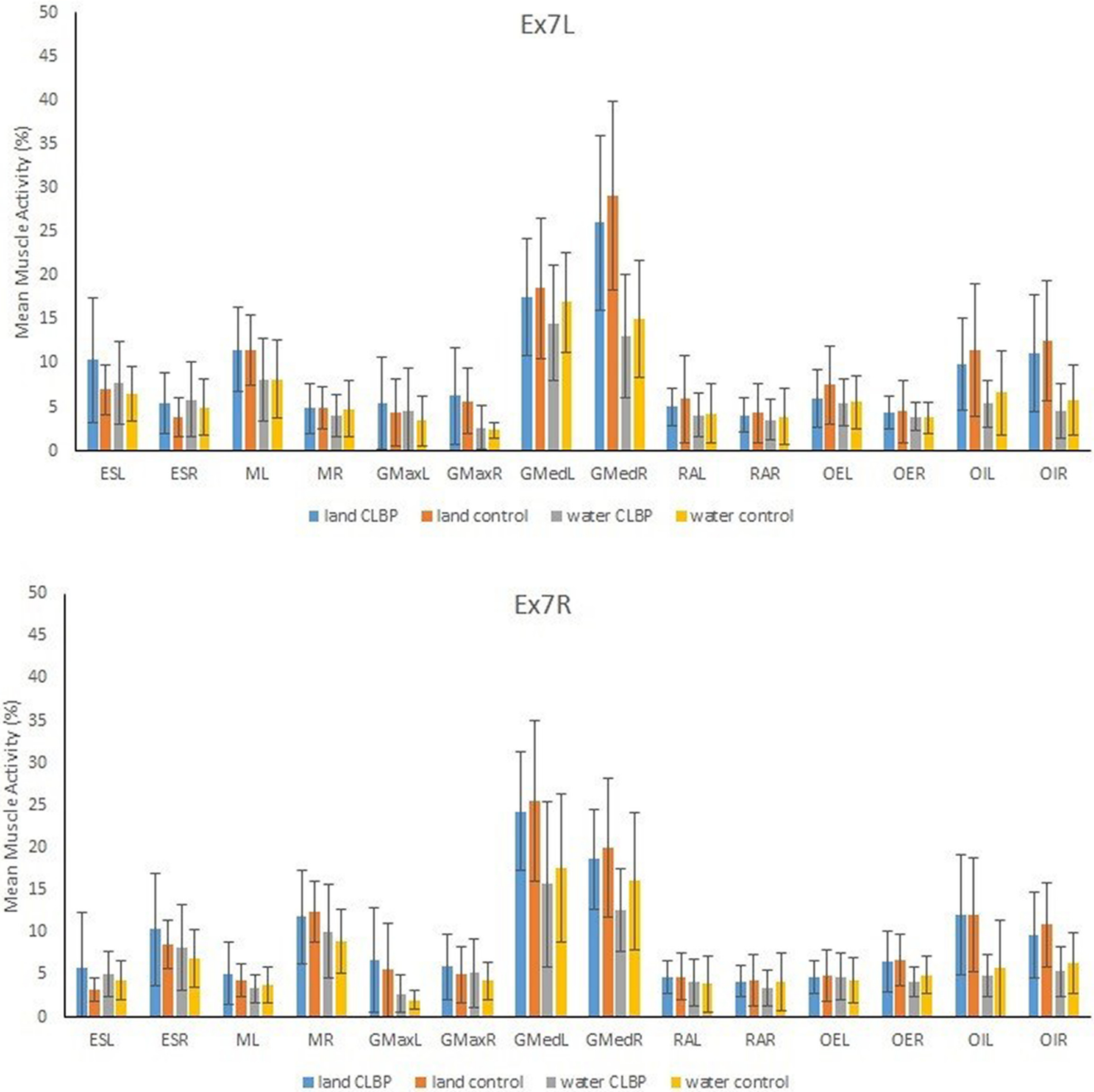
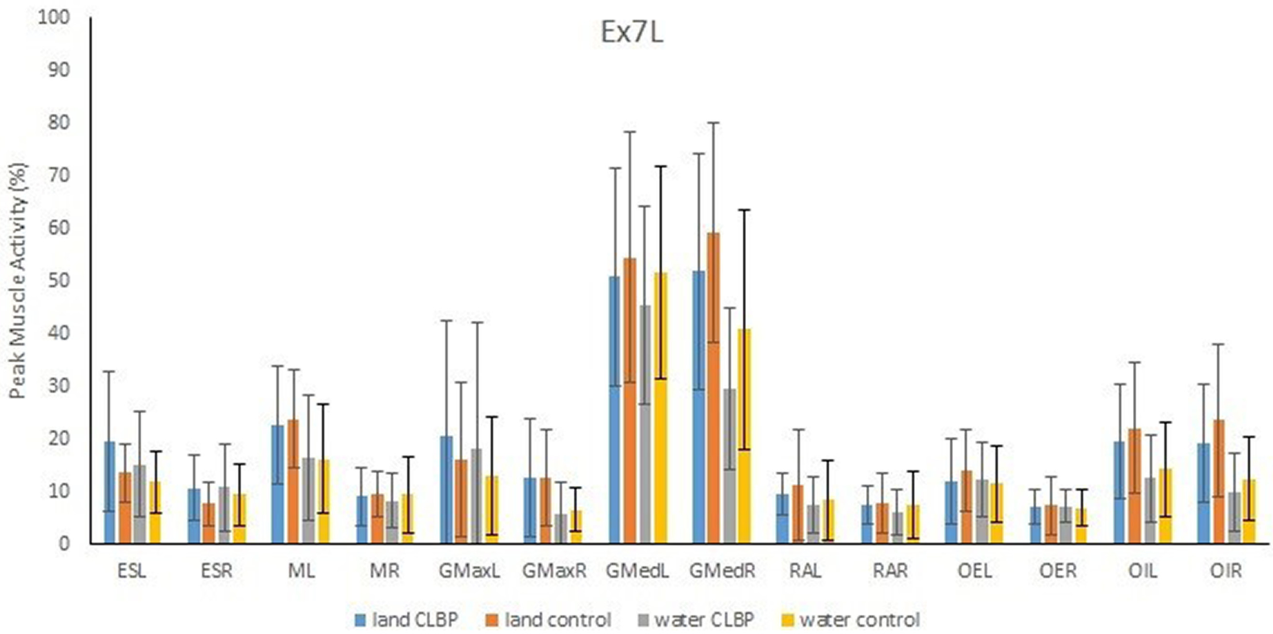



**Figure 2.**
Mean muscle activity for the chronic lower back pain (CLBP) group and control group during dynamic lower limb exercise 7 (hip abduction). ESL = left erector spinae; ESR = right erector spinae; GMaxL = left gluteus maximus; GMaxR = right gluteus maximus; GMedL = left gluteus medius; GMedR = right gluteus medius; ML = left multifidus; MR = right multifidus; OEL = left external oblique; OER = right external oblique; OIL = left internal oblique; OIR = right internal oblique; RAL = left rectus abdominis; RAR = right rectus abdominis.

EMG data and Figure 3 the peak EMG data recorded in the water and on land for Ex7 (hip abduction). eFigures 1 and 2 (available at https://academic.oup.com/ptj) show the mean and peak EMG data for all exercises. The RPE, HR, and pain data are shown in Table 1.

## Differences Between CLBP and Control Groups

In most cases, muscle activation, RPE, and HR values were not different between the CLBP and control groups. The only exceptions were the mean left ES activations in Ex2 ($P$ = .007; 95% CI = 0.59–4.83; partial $\eta^2$ = 0.105) and



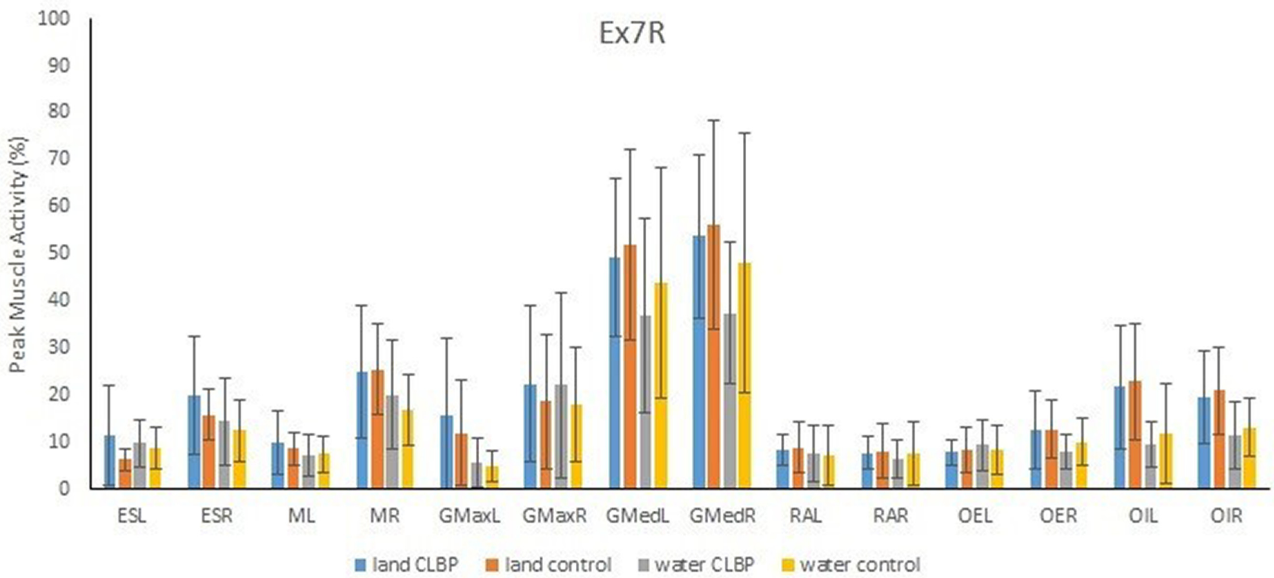




**Figure 3.**
Peak muscle activity for the chronic lower back pain (CLBP) group and control group during dynamic lower limb exercise 7 (hip abduction). ESL = left erector spinae; ESR = right erector spinae; GMaxL = left gluteus maximus; GMaxR = right gluteus maximus; GMedL = left gluteus medius; GMedR = right gluteus medius; ML = left multifidus; MR = right multifidus; OEL = left external oblique; OER = right external oblique; OIL = left internal oblique; OIR = right internal oblique; RAL = left rectus abdominis; RAR = right rectus abdominis.

RPE in Ex6 ($P$ = .022; 95% CI = 0.26–3.12; partial $\eta^2$ = 0.133), which were greater in the CLBP group.

## Differences Between Aquatic and Land Environments

Significant differences between environments are shown in Table 2 for EMG and in Table 3 for HR and RPE. There were no differences in muscle activation between water and land in about two-thirds of the cases. Significantly higher mean or peak activation for some muscles on land was observed in ~29% and in the water in ~5% of comparisons. Higher activation in the water was recorded for left and right external oblique muscles (Ex3, Ex5), for left rectus abdominis (Ex3, Ex4), and for erector spinae

**Table 1.**
Heart Rate, Rate of Perceived Exertion, and Pain[a]

| Water Exercises | | | | | | Land Exercises | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Exercise[b] | HR[c] | | RPE[d] | | Pain[e] | Exercise[b] | HR[c] | | RPE[d] | | Pain[e] |
| | CLBP Group | Control Group | CLBP Group | Control Group | CLPB Group | | CLBP Group | Control Group | CLBP Group | Control Group | CLPB Group |
| 1L | 75 (8) | 70 (11) | 10 (2) | 9 (2) | 3.4, 3.8 | 1L | 86 (9) | 89 (15) | 11 (2) | 10 (2) | 0.9, 1.1, 1.4, 3.1 |
| 1R | 73 (8) | 68 (13) | 10 (2) | 10 (2) | | 1R | 89 (9) | 90 (15) | 10 (2) | 10 (2) | 1.3, 1.9, 3.4 |
| 2 | 75 (9) | 70 (14) | 10 (2) | 10 (2) | 2.6 | 2 | 85 (11) | 85 (13) | 8 (2) | 8 (2) | |
| 3 | 77 (9) | 73 (11) | 10 (2) | 9 (2) | 1.8 | 3 | 82 (11) | 82 (15) | 9 (2) | 9 (2) | 2.9 |
| 4 | 85 (7) | 81 (11) | 11 (2) | 10 (2) | | 4 | 100 (10) | 99 (16) | 12 (2) | 11 (2) | 6.9 |
| 5 | 79 (10) | 76 (12) | 11 (3) | 10 (2) | | 5 | 85 (10) | 89 (11) | 10 (2) | 9 (2) | 1.6, 1.7 |
| 6 | 74 (11) | 68 (11) | 14 (3) | 12 (3) | | 6 | 91 (9) | 90 (12) | 13 (2) | 12 (3) | 1.1 |
| 7L | 76 (11) | 72 (12) | 9 (2) | 9 (2) | 1.4 | 7L | 87 (10) | 88 (13) | 11 (2) | 11 (2) | 1.5 |
| 7R | 76 (9) | 73 (12) | 10 (2) | 9 (2) | 0.8, 1.9 | 7R | 87 (8) | 90 (15) | 11 (2) | 10 (2) | |
| 8L | 68 (9) | 70 (12) | 9 (2) | 9 (2) | 1.2 | 8L | 85 (8) | 88 (13) | 10 (2) | 9 (2) | 1.8, 2.0, 6.8 |
| 8R | 69 (9) | 70 (13) | 9 (2) | 9 (2) | 0.9, 1.1, 1.1 | 8R | 85 (8) | 89 (15) | 10 (2) | 9 (2) | 1.4, 1.6, 2.4 |
| 9L | 75 (11) | 72 (14) | 10 (2) | 10 (2) | | 9L | 89 (9) | 94 (14) | 12 (2) | 11 (3) | |
| 9R | 76 (10) | 74 (12) | 10 (2) | 10 (3) | | 9R | 89 (9) | 92 (14) | 12 (2) | 11 (3) | |
| 10 | 80 (12) | 82 (11) | 10 (3) | 11 (3) | | 10 | 88 (11) | 90 (14) | 11 (3) | 10 (2) | 1.2, 3.9, 4.2 |
| 11 | 74 (11) | 70 (13) | 11 (3) | 11 (3) | | 11 | 80 (8) | 80 (12) | 12 (2) | 10 (3) | 1.3 |

[a]As recorded at the end of dynamic exercises with upper extremity (exercises 1–6) and lower extremity (exercises 7–11) movements. Values are reported as mean (SD) unless otherwise indicated. CLBP = chronic low back pain; HR = heart rate; L = left side; R = right side; RPE = rate of perceived exertion.
[b]Refer to Figure 1 for descriptions of exercises.
[c]Reported as beats/min.
[d]Reported as scores on the Borg scale (from 6 to 20).
[e]Pain values shown are all of the nonzero values reported (on the visual analog scale, scored from 1 to 10), with blank cells indicating no pain report.

and rectus abdominis (Ex11). With the exception of Ex5, higher activation on land was recorded for some muscles in all other exercises. HR was higher on land for all exercises. Perceived exertion was higher in the water for 3 exercises (Ex2, Ex3, Ex5), higher on land for 6 exercises (Ex7L/R, Ex8L/R, Ex9L/R), and not different for the remaining 6 exercises.

### Pain in the CLBP Group

Pain level was generally low and not significantly different between environments (mean [SD] water pain level = 1.8[1.0]; land pain level = 2.4[1.6]). Pain was reported more than twice as frequently when exercising on land, with 23 reports of pain on land (7.7% of cases) and 11 reports of pain in the water (3.7% of cases).

## Discussion

Low back pain affects millions of people worldwide and causes pain, disability, and a decrease in quality of life. Although exercise is recommended for the treatment and management of CLBP, information on appropriateness of rehabilitative aquatic exercises in activating trunk and gluteal muscles is lacking. To our knowledge, this was the first study to measure trunk and gluteal muscle activation in people with CLBP when performing rehabilitative aquatic exercises, and to report the associated pain, intensity, and perceived exertion. The inclusion of similar land exercises and of a group of healthy controls, as well as the use of rigorous advanced methods, provide confidence in the findings and their practical applications. This robust set of data can positively affect practice, inform exercise prescription, and improve effectiveness of rehabilitation.

In summary, the between-group comparison in the present study showed no differences between CLBP and control groups. The between-environment comparison revealed no differences in muscle activation in two-thirds of the cases, but activation was higher on land in 29% and in the water in 5% of comparisons. HR was higher on land than in the water, but perceived exertion showed a mixed pattern, with neither environment producing consistently higher values than the other. Pain levels were low but pain was reported more than twice as frequently when exercising on land.

**Table 2.**
Significant Differences Between Land and Water Environments in Mean and Peak Electromyographic (EMG) Amplitudes for Dynamic Exercises[a]

| Exercise[b] | Muscle | Significant Differences[c] in: | | | | | |
|---|---|---|---|---|---|---|---|
| | | Mean EMG | | | Peak EMG | | |
| | | *P* | 95% CI | Effect Size | *P* | 95% CI | Effect Size |
| 1L | ESR | .001 | −6.68 to −3.56 | 0.529 | | | |
| | MR | .001 | −4.70 to −1.97 | 0.358 | | | |
| | GMaxR | .001 | −1.39 to −0.40 | 0.268 | | | |
| | GMedR | .001 | −2.06 to −0.71 | 0.284 | | | |
| | OER | .001 | −7.49 to −2.63 | 0.297 | | | |
| | OIL | .001 | −7.59 to −3.15 | 0.384 | | | |
| | OIR | .001 | −4.63 to −1.94 | 0.391 | .006 | −8.32 to −1.69 | 0.238 |
| 1R | ESL | .001 | −6.89 to −3.58 | 0.493 | .004 | −8.14 to −2.19 | 0.234 |
| | ML | .001 | −5.80 to −2.52 | 0.415 | .001 | −8.00 to −1.60 | 0.250 |
| | GMedL | .003 | −3.49 to −1.18 | 0.295 | | | |
| | OIR | .008 | −8.39 to −2.95 | 0.309 | | | |
| 2 | GMaxL | .004 | −1.44 to −0.41 | 0.266 | | | |
| | GMaxR | .001 | −1.65 to −0.65 | 0.384 | .001 | −2.43 to −0.87 | 0.293 |
| | GMedL | .002 | −2.22 to −0.78 | 0.284 | .008 | −3.11 to −0.89 | 0.201 |
| | GMedR | .001 | −1.98 to −0.84 | 0.381 | .003 | −2.75 to −0.84 | 0.254 |
| 3 | GMedR | .002 | −1.59 to −0.58 | 0.283 | | | |
| | RAL | **.008** | **0.57–2.11** | **0.220** | **.003** | **1.97–5.48** | **0.257** |
| | OEL | **.004** | **1.64–3.85** | **0.349** | **.002** | **3.43–7.98** | **0.362** |
| | OER | **.009** | **1.10–2.80** | **0.269** | **.004** | **2.29–6.11** | **0.277** |
| | OIR | .005 | −2.78 to −0.60 | 0.219 | | | |
| 4 | ESL | .001 | −8.37 to −3.62 | 0.425 | .002 | −16.64 to −5.06 | 0.265 |
| | ESR | .001 | −9.26 to −4.10 | 0.373 | | | |
| | ML | .001 | −7.55 to −4.10 | 0.536 | .001 | −17.07 to −8.39 | 0.387 |
| | MR | .001 | −8.88 to −4.89 | 0.572 | .001 | −21.57 to −11.41 | 0.444 |
| | GMaxL | .001 | −3.75 to −2.26 | 0.625 | .001 | −12.74 to −7.91 | 0.637 |
| | GMaxR | .001 | −3.61 to −2.44 | 0.715 | .001 | −12.53 to −8.20 | 0.728 |
| | GMedL | .001 | −3.18 to −1.28 | 0.358 | .001 | −9.88 to −3.89 | 0.404 |
| | GMedR | .001 | −2.79 to −1.08 | 0.341 | .001 | −8.74 to −3.62 | 0.323 |
| | RAL | **.001** | **3.07–6.91** | **0.418** | **.001** | **19.17–36.46** | **0.476** |
| 5 | OEL | **.001** | **1.98–3.72** | **0.437** | **.002** | **4.34–8.80** | **0.454** |
| | OER | **.002** | **1.69–3.35** | **0.442** | **.001** | **3.90–8.38** | **0.465** |
| 6 | ESL | .005 | −4.20 to −1.37 | 0.299 | | | |
| | ESR | .002 | −4.91 to −1.85 | 0.288 | | | |
| | ML | .002 | −2.10 to −0.74 | 0.345 | | | |
| | MR | .001 | −2.83 to −1.28 | 0.439 | .001 | −5.65 to −1.85 | 0.336 |
| | RAL | .001 | −35.29 to −8.76 | 0.517 | .001 | −139.60 to −72.92 | 0.556 |
| | RAR | .001 | −24.8 to −12.7 | 0.521 | .001 | −95.11 to −54.98 | 0.602 |

(continued)

**Table 2.**
Continued

| Exercise[b] | Muscle | Significant Differences[c] in: | | | | | |
|---|---|---|---|---|---|---|---|
| | | Mean EMG | | | Peak EMG | | |
| | | *P* | 95% CI | Effect Size | *P* | 95% CI | Effect Size |
| | OER | .002 | −7.78 to −1.68 | 0.242 | .002 | −27.94 to −6.31 | 0.267 |
| | OIL | .001 | −13.90 to −7.90 | 0.559 | .001 | −48.82 to −26.05 | 0.571 |
| | OIR | .001 | −15.82 to −8.38 | 0.545 | .001 | −58.28 to −29.99 | 0.491 |
| 7L | ML | .001 | −5.00 to −1.74 | 0.288 | .001 | −10.32 to −3.65 | 0.290 |
| | GMaxR | .001 | −5.15 to −2.06 | 0.357 | .002 | −10.01 to −3.38 | 0.291 |
| | GMedR | .001 | −16.98 to −10.10 | 0.569 | .002 | −28.90 to −12.15 | 0.343 |
| | OIL | .001 | −6.91 to −2.93 | 0.376 | .001 | −11.27 to −4.14 | 0.323 |
| | OIR | .001 | −8.53 to −5.15 | 0.570 | .001 | −14.07 to −6.95 | 0.417 |
| 7R | MR | .001 | −3.85 to −1.40 | 0.307 | .001 | −9.18 to −4.29 | 0.411 |
| | GMaxL | .004 | −5.59 to −2.04 | 0.352 | .007 | −12.66 to −4.70 | 0.342 |
| | GMedL | .001 | −11.38 to −4.99 | 0.349 | | | |
| | GMedR | .003 | −7.31 to −2.77 | 0.301 | | | |
| | OER | .002 | −3.32 to −1.31 | 0.361 | | | |
| | OIL | .001 | −8.85 to −4.88 | 0.500 | .001 | −15.70 to −8.00 | 0.451 |
| | OIR | .001 | −5.90 to −3.37 | 0.535 | .001 | −10.77 to −5.86 | 0.515 |
| 8L | ML | .009 | −4.04 to −0.62 | 0.175 | | | |
| | GMaxL | .006 | −3.79 to −0.60 | 0.184 | | | |
| | GMaxR | .002 | −2.14 to −0.73 | 0.250 | | | |
| | GMedR | .001 | −14.42 to −9.06 | 0.677 | .001 | −24.09 to −14.24 | 0.589 |
| | OIL | .001 | −6.76 to −3.43 | 0.450 | .001 | −11.85 to −5.33 | 0.385 |
| | OIR | .001 | −7.41 to −4.41 | 0.574 | .002 | −11.40 to −6.21 | 0.524 |
| 8R | GMaxR | .008 | −3.73 to −0.60 | 0.170 | | | |
| | GMedL | .001 | −9.70 to −5.71 | 0.591 | .001 | −14.43 to −6.27 | 0.400 |
| | GMedR | .004 | −5.84 to −1.43 | 0.251 | | | |
| | OER | .003 | −1.88 to −0.63 | 0.283 | .007 | −3.31 to −0.78 | 0.201 |
| | OIL | .002 | −7.75 to −4.15 | 0.495 | .001 | −12.56 to −6.24 | 0.453 |
| | OIR | .001 | −5.60 to −2.94 | 0.506 | .001 | −9.80 to −4.93 | 0.462 |
| 9L | GMaxL | .001 | −4.45 to −2.07 | 0.426 | .001 | −10.12 to −3.67 | 0.347 |
| | GMedL | .001 | −12.21 to −6.92 | 0.581 | .001 | −20.43 to −8.84 | 0.392 |
| | OIL | .001 | −7.23 to −3.61 | 0.443 | .001 | −11.95 to −4.80 | 0.354 |
| | OIR | .001 | −3.98 to −2.02 | 0.490 | .001 | −5.97 to −2.69 | 0.410 |
| 9R | GMaxR | .001 | −5.25 to −2.82 | 0.496 | .002 | −10.99 to −4.72 | 0.377 |
| | GMedR | .001 | −15.99 to −9.58 | 0.602 | .001 | −26.88 to −11.33 | 0.338 |
| | OIL | .001 | −5.29 to −2.05 | 0.315 | .001 | −8.35 to −2.83 | 0.296 |
| | OIR | .001 | −7.44 to −4.10 | 0.619 | .001 | −12.18 to −5.93 | 0.534 |
| 10 | OIL | .001 | −7.57 to −3.87 | 0.460 | .002 | −19.83 to −9.44 | 0.441 |
| | OIR | .001 | −7.44 to −3.79 | 0.520 | .001 | −20.72 to −10.85 | 0.549 |
| 11 | ESL | **.001** | **2.43–5.32** | **0.390** | **.005** | **1.94–7.39** | **0.231** |
| | ESR | **.002** | **2.49–6.09** | **0.328** | **.008** | **0.95–8.17** | **0.184** |

(continued)

**Table 2.**
Continued

| Exercise[b] | Muscle | Significant Differences[c] in: | | | | | |
|---|---|---|---|---|---|---|---|
| | | Mean EMG | | | Peak EMG | | |
| | | *P* | 95% CI | Effect Size | *P* | 95% CI | Effect Size |
| | MR | | | | .004 | −3.58 to −0.56 | 0.201 |
| | GMedR | .001 | −3.04 to −1.33 | 0.376 | .001 | −9.20 to −3.55 | 0.349 |
| | RAL | **.001** | **3.13–6.14** | **0.510** | **.001** | **5.84–10.67** | **0.507** |
| | RAR | **.001** | **3.66–7.02** | **0.520** | **.001** | **6.44–12.44** | **0.547** |

[a]Exercises included upper limb (exercises 1–6) and lower limb (exercises 7–11) movements. ESL = left erector spinae; ESR = right erector spinae; GMaxL = left gluteus maximus; GMaxR = right gluteus maximus; GMedL = left gluteus medius; GMedR = right gluteus medius; ML = left multifidus; MR = right multifidus; OEL = left external oblique; OER = right external oblique; OIL = left internal oblique; OIR = right internal oblique; RAL = left rectus abdominis; RAR = right rectus abdominis.
[b]Refer to Figure 1 for descriptions of exercises.
[c]Negative 95% CIs indicate greater EMG amplitudes on land. Positive 95% CIs (shown in bold type) indicate greater EMG amplitudes in water. Empty cells indicate no significant difference.

**Table 3.**
Significant Differences Between Land and Water Environments in Heart Rate and Rate of Perceived Exertion During Dynamic Exercises[a]

| Exercise[b] | Significant Differences[c] in: | | | | | |
|---|---|---|---|---|---|---|
| | Heart Rate | | | Rate of Perceived Exertion | | |
| | *P* | 95% CI | Effect Size | *P* | 95% CI | Effect Size |
| 1L | <.001 | 10.05–19.35 | 0.533 | | | |
| 1R | <.001 | 13.07–24.11 | 0.565 | | | |
| 2 | <.001 | 7.64–16.13 | 0.465 | **<.001** | **−2.63 to −0.94** | **0.331** |
| 3 | <.001 | 2.91–12.08 | 0.228 | **.001** | **−1.09 to −0.13** | **0.151** |
| 4 | <.001 | 12.44–20.83 | 0.643 | | | |
| 5 | <.001 | 4.57–13.65 | 0.321 | **.033** | **−1.35 to −0.06** | **0.117** |
| 6 | <.001 | 16.87–26.32 | 0.705 | | | |
| 7L | <.001 | 6.63–17.24 | 0.559 | <.001 | 0.79–2.27 | 0.320 |
| 7R | <.001 | 10.05–17.68 | 0.594 | .001 | 0.63–2.08 | 0.278 |
| 8L | <.001 | 13.76–20.57 | 0.744 | .046 | 0.01–1.42 | 0.103 |
| 8R | <.001 | 13.42–20.81 | 0.711 | .026 | 0.09–1.38 | 0.127 |
| 9L | <.001 | 12.90–22.73 | 0.600 | .001 | 0.92–2.49 | 0.344 |
| 9R | <.001 | 10.10–19.18 | 0.543 | <.001 | 0.63–2.26 | 0.259 |
| 10 | <.001 | 3.16–12.57 | 0.237 | | | |
| 11 | <.001 | 4.32–12.24 | 0.347 | | | |

[a]Exercises included upper extremity (exercises 1–6) and lower extremity (exercises 7–11) movements. L = left side; R = right side.
[b]Refer to Figure 1 for descriptions of exercises.
[c]Heart rates were always significantly higher on land. Rates of perceived exertion were significantly higher on land unless indicated otherwise. Rates of perceived exertion (shown in bold type) were significantly higher in water. Empty cells indicate no significant difference.

## Differences Between CLBP and Control Groups

The only significant differences between the 2 groups were the mean ES values for 1 exercise (out of 840 EMG comparisons) and RPE for 1 exercise (out of 30 comparisons). This is well within the experiment-wise error rate of false significant differences expected due to possible statistical type I error (approximately 8 false significant differences for EMG and 2 for RPE). Hence, it can be stated that participants with CLBP had the same muscle activation, HR, and perceived exertion as healthy controls when exercising in the water and on land. Because this is the first such data set for an aquatic environment, it suggests that exercising in the water can be beneficial for rehabilitation and strengthening by allowing people with CLBP to perform the exercises and activate muscles without their condition adversely affecting them.

In previous studies comparing muscle activity between CLBP and control groups during similar land exercises, ~80% of the comparisons showed no differences.[34–36] When differences were reported, the patterns were mixed, at times even within the same exercise, with no group displaying consistently higher activation. Ng et al[35] stated that this possibly relates to the variance in impaired coordination of people with CLBP and the fact that trunk muscles can act as prime movers, antagonists, or stabilizers. In line with some of their findings, and considering that several different exercises have been tested among studies, it is also possible that slight variations in exercises could elicit different patterns of activation for some muscles in CLBP groups.

It is worth noting that, in the present study, participants with CLBP exercised recreationally despite their CLBP and were classified as having moderate disability and low risk of kinesiophobia. This implies that they would typically respond well to self-management[37] and could further explain the absence of between-group differences. It has been suggested that subgrouping people with LBP based on clinical findings might be useful in helping to select the most appropriate treatment.[38] Thus, future research should seek to confirm if the current findings reflect CLBP populations with greater disability and/or fear of movement, or even a subgroup of acute sudden-onset pain.

## Differences Between Aquatic and Land Environments

**Muscle activation.** No significant differences were found between environments in ~66% of all muscle activation comparisons. There was greater activation on land in ~29% of comparisons and greater activation in the water in ~5% of comparisons.

Mean Ex1 activity was greater on land for the contralateral spinal extensors, whereas the ipsilateral spinal extensors were not significantly different. There was not the same consistency for the remaining muscles, as activation was greater on land for 3 of the 4 oblique abdominal muscles in Ex1L, but just 1 in Ex1R. One of the reasons for the side differences could be that there were 3 reports of pain for Ex1R on land but none in the water. Interestingly, Ex2 showed differences for the gluteal muscles only (greater on land), suggesting that hydrostatic pressure probably offers sufficient support to maintain balance during sagittal upper extremity movement despite the drag and turbulence created. Ex3 and Ex5 that incorporated alternating upper extremity movements required similar activation in the water and land for the spinal extensors and majority of gluteal muscles (except that external oblique activation was greater in the water). Greater activation on land was needed in spinal extensors and gluteal muscles for Ex4, which involved a movement assisted by gravity (land) or buoyancy (water) in the first phase. Hence, performing a squat with upper extremity movement, similar to a lifting task, is perhaps initially better trained in an aquatic environment if spinal extensor overactivity is problematic or painful. Ex6 might pose similar benefits due to greater abdominal and spinal extensor activity on land. If an abdominal strengthening exercise was required for rehabilitation but a land program was too advanced, then this water exercise could offer a suitable intermediate step.

In the unilateral lower extremity exercises of hip abduction, extension, and single-leg squat (Ex7–9), gluteal activity was the same or greater on land. This might not be surprising due to the effects of buoyancy assisting the concentric phase, which would normally require increased gluteal effort in the dynamically moving lower extremity on land to control against gravity. In addition, hydrostatic pressure offers greater support in the water, thereby attenuating the need for gluteal activity to maintain balance in the static supporting lower extremity. These findings might suggest that, to increase gluteal activity, unilateral hip exercises should be performed on land rather than in the water, as gluteal weakness has been observed in patients with CLBP.[11,39] The ES and RA had greater activation in the water for Ex11, perhaps suggesting a greater "splinting" or coactivation of the large force-producing sagittal trunk muscles. Such a trunk stiffening strategy has been observed in people with LBP[40] and might not be desirable. However, it is also possible that the ES and RA activity implied abdominal bracing, because with the body being partially supported by the dumbbells, muscles such as latissimus dorsi and iliopsoas might have been activated more. Finally, another possibility is that the water alternative of this exercise required greater postural control due to buoyancy effects displacing the dumbbells, thus making it more challenging. In this case, the aquatic version of the exercise could be considered as a progression of the land exercise.

Overall, muscle activation in the water was at least similar to that on land in 71% of all muscle comparisons. This is contrary to some previous research findings and assumptions that aquatic exercise produces lower muscle activation.[22,24] It is important to note that lower activation in the water in previous research had sometimes been partially attributed to the challenges of waterproofing electrodes, which could cause a decrease in the recorded EMG values in the water. The EMG system in the present study was waterproof by design, minimizing such problems. Introducing an element of added resistance in several of the aquatic exercises in the present study could also be another reason that, contrary to previous assumptions, activation in the water was usually not lower than that on land. This suggestion is consistent with some other studies, where higher muscle activity has often been reported when resistance was added in aquatic exercises.[24,25] Although research findings in this area should always be interpreted with caution given the limitations of comparing aquatic and land exercises, the present data suggest that aquatic exercise should not be regarded as less effective than land exercise in activating trunk and gluteal muscles. The level of activation can be muscle-, exercise-, or resistance-dependent. Finally, as summarized by Bressel et al,[22] levels of activation of 25% or less have been shown to be sufficient to improve motor control and endurance aspects of some trunk muscles, and are of an intensity that maximally stiffens segmental joints of the spine. Thus, the exercises that were used in the present study seem, overall, to produce sufficient levels of activation for subsequent improvements.

**Heart rate and perceived exertion.** Heart rate was lower in the water. This was anticipated as water immersion is generally expected to reduce HR.[41] Although comparison of HR values in the water and on land has been reported in other studies,[41] to our knowledge, the present study is the first in this area to compare perceived exertion between these 2 environments. A mixed pattern was observed, with no environment producing consistently higher values than the other. Perceived exertion scores for individual participants ranged from 6 to 19 (“no exertion” to “extremely hard”) in both environments. In some exercises, when higher exertion was recorded in 1 environment there were also more muscles with higher activation in that environment. However, in most exercises, higher perceived exertion for an environment was not accompanied by higher muscle activation, so differences in muscle activation did not seem to be linked to differences in perceived exertion.

**Pain in the CLBP group.** Pain level was generally low and not different between environments, despite a tendency for the nonzero values to be higher on land (2.4 vs 1.8). Pain was reported more than twice as often on land (7.7%) than in the water (3.7%), suggesting that an aquatic environment could be more appropriate than land for avoiding the adverse effects of pain when exercising. In previous studies, pain level has been reported to be either similar between environments or lower in an aquatic environment,[13,18] with 1 study reporting that the aquatic environment produced about half the reports of pain of the land environment.[17]

Right hip extension was the only aquatic exercise to have more than 2 pain reports, albeit with the pain level being very low (1.0). In contrast, at least 3 participants (≥15% of the group) reported pain in one-third of all land exercises (mean level from 1.6 to 3.5). Although this requires further investigation to be confirmed for other CLBP groups, such findings are potentially relevant for patients with CLBP of greater severity or irritability of symptoms, where exercising in water could be the only medium where pain can be maintained below a manageable threshold. It is also possible that the water provided better support in exercises such as Ex8, helping to maintain a more stable and neutral trunk and pelvis.

## Limitations and Future Directions

We examined a male CLBP population that had mild-to-moderate disability, using exercises with specific cadence and resistance. Future studies could expand to participants of both sexes with different levels of disability and classification, and explore any differences when resistance or speed of movement are altered. The exercises in the present study should now be used to inform rehabilitation programs in the water and on land, and to evaluate their effectiveness and cost-effectiveness compared with other types of CLBP treatment and management.

## Conclusion

There were no differences between people with and without CLBP when exercising in the water or on land. For the between-environment comparison, HR was higher on land but no environment produced consistently higher values than the other for perceived exertion. Muscle activation was different between environments in about one-third of comparisons (greater on land in 29% and in the water in 5% of cases). This diversity indicates that aquatic exercises should not be assumed to be less strenuous or less effective in activating muscles than land exercises. Pain was reported more than twice as frequently when exercising on land, suggesting that the aquatic environment might be more appropriate for patients with kinesiophobia or when pain is a limiting factor.

## Author Contributions

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Clerical/secretarial support: S.G. Psycharakis
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## Ethics Approval

Ethical approval was obtained from the ethics committee of the Moray House School of Education, at the University of Edinburgh. All participants read the participant information sheet and signed an informed consent form before commencing the study.

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## Disclosures

The authors completed the ICJME Form for Disclosure of Potential Conflicts of Interest and reported no conflicts of interest.

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## References


1. Waller B. Therapeutic aquatic exercise in the treatment of low back pain: a systematic review. *Clin Rehabil*. 2009;23:3–14.
2. Woolf AD, Pfleger B. Burden of major musculoskeletal conditions. *Bull World Health Organ*. 2003;81:646–656.
3. Guo HR, Tanaka S, Halperin WE et al. Back pain prevalence in US industry and estimates of lost workdays. *Am J Public Health*. 1999;89:1029–1035.
4. Health and Safety Executive. LFS- Labour Force Survey: self-reported work-related ill health and workplace injuries. Index of LFS tables. http://www.hse.gov.uk/statistics/lfs/index.htm. Accessed July 19, 2018.
5. Katz JN. Lumbar disc disorders and low-back pain: socioeconomic factors and consequences. *J Bone Joint Surg Am*. 2006;88:21–24.
6. O'Sullivan P. Diagnosis and classification of chronic low backpain disorders: maladaptive movement and motor control impairments as underlying mechanism. *Manual Ther*. 2005;10:242–255.
7. Costa LC, Maher CG, McAuley JH, et al. Prognosis for patients with chronic low back pain: inception cohort study. *BMJ*. 2009;339:b3829.
8. Hides JA, Stanton WR, Mendis MD et al. Effect of motor control training on muscle size and football games missed from injury. *Med Sci Sports Exerc*. 2012;44:1141–1149.
9. Macedo LG, Latimer J, Maher CG, et al. Effect of motor control exercises versus graded activity in patients with chronic nonspecific low back pain: a randomized controlled trial. *Phys Ther*. 2012;92:363–377.
10. D'Hooge R, Hodges P, Tsao H et al. Altered trunk muscle coordination during rapid trunk flexion in people in remission of recurrent low back pain. *J Electromyogr Kinesiol*. 2013;23:173–181.
11. Nourbakhsh MR, Arab AM. Relationship between mechanical factors and incidence of low back pain. *J Orthop Sports Phys Ther*. 2002;32:447–460.
12. Eversden L, Maggs F, Nightingale P et al. A pragmatic randomised controlled trial of hydrotherapy and land exercises on overall well being and quality of life in rheumatoid arthritis. *BMC Musculoskelet Disord*. 2007;8:23.
13. Dundar U, Solak O, Yigit I et al. Clinical effectiveness of aquatic exercise to treat chronic low back pain: a randomized controlled trial. *Spine*. 2009;34:1436–1440.
14. Baena-Beato PA, Ártero EG, Arroyo-Morales M et al. Aquatic therapy improves pain, disability, quality of life, body composition and fitness in sedentary adults with chronic low back pain. A controlled clinical trial. *Clin Rehabil*. 2014;28:350–360.
15. Bayraktar D, Guclu-Gunduz A, Lambeck J et al. A comparison of water-based and land-based core stability exercises in patients with lumbar disc herniation: a pilot study. *Disabil Rehabil*. 2016;38:1163–1171.
16. Bello A, Kalu NH, Adegoke BOA, et al. Hydrotherapy versus land-based exercises in the management of chronic low back pain: a comparative study. *J Musculoskelet Res*. 2010;13:159–165.
17. Granath AB, Hellgren MSE, Gunnarsson RK. Water aerobics reduces sick leave due to low back pain during pregnancy. *J Obstet Gynecol Neonatal Nurs*. 2006;35:465–471.
18. Sjogren T, Long N, Story I et al. Group hydrotherapy versus group land-based treatment for chronic low back pain. *Physiotherapy Res Int*. 1997;2:207–217.
19. Hettinga DM, Jackson A, Moffett JK, et al. A systematic review and synthesis of higher quality evidence of the effectiveness of exercise interventions for non-specific low back pain of at least 6 weeks' duration. *Phys Ther Rev*. 2013;12:221–232.
20. National Institute of Health and Care Excellence. Low back pain and sciatica in over 16s: assessment and management. https://www.nice.org.uk/guidance/ng59/chapter/Recommendations. Published November 2016. Accessed July 19, 2018.
21. Van Middelkoop M, Rubinstein SM, Verhagen AP et al. Exercise therapy for chronic nonspecific low-back pain. *Best Pract Res Clin Rheumato*. 2010;24:193–204.
22. Bressel E, Dolny DG, Gibbons M. Trunk muscle activity during exercises performed on land and in water. *Med Sci Sports Exerc*. 2011;43:1927–1932.
23. Kaneda K, Sato D, Wakabayashi H et al. EMG activity of hip and trunk muscles during deep-water running. *J Electromyogr Kinesiol*. 2009;19:1064–1070.
24. Masumoto K, Takasugi S, Hotta N et al. Muscle activity and heart rate response during backward walking in water and on dry land. *Eur J Appl Physiol*. 2005;94:54–61.
25. Colado JC, Tella V, Triplett NT. A method for monitoring intensity during aquatic resistance exercises. *J Strength Cond Res*. 2008;22:2045–2049.
26. Bressel E, Dolny DG, Vandenberg C et al. Trunk muscle activity during spine stabilization exercises performed in a pool. *Phys Ther Sport*. 2012;13:67–72.
27. Cholewicki J, Silfies SP, Shah RA, et al. Delayed trunk muscle reflex responses increase the risk of low back injuries. *Spine*. 2005;30:2614–2620.
28. Faul F. *GPower 3.1.9.2*. Universität Kiel: 2014.
29. Seniam. Recommendations for sensor locations on individual muscles. http://www.seniam.org. Accessed July 19, 2018.
30. Boccia G, Rainoldi A. Innervation zones location and optimal electrodes position of obliquus internus and obliquus externus abdominis muscles. *J Electromyogr Kinesiol*. 2014;24:25–30.
31. Huebner A, Faenger B, Schenk P et al. Alteration of surface EMG amplitude levels of five major trunk muscles by defined electrode location displacement. *J Electromyogr Kinesiol*. 2015;25:214–223.
32. Dankaerts W, O'Sullivan PB, Burnett AF et al. Reliability of EMG measurements for trunk muscles during maximal and sub-maximal voluntary isometric contractions in healthy controls and CLBP patients. *J Electromyogr Kinesiol*. 2004;14:333–342.
33. Richardson JTE. Eta squared and partial eta squared as measures of effect size in educational research. *Educ Res Review*. 2011;6:135–147.
34. Marshall PWM, Desai I. Electromyographic analysis of upper body, lower body, and abdominal muscles during advanced swiss ball exercises. *J Strength Cond Res*. 2014;24:1537–1545.
35. Ng JKF, Richardson CA, Parnianpour M et al. EMG activity of trunk muscles and torque output during isometric axial rotation exertion: a comparison between back pain patients and matched controls. *J Orthop Res*. 2002;20:112–121 02.

**36.** Silfies SP, Squillante D, Maurer P, Westcott S et al. Trunk muscle recruitment patterns in specific chronic low back pain populations. *Clin Biomech*. 2005;20:465–473.

**37.** Foster NE, Mullis R, Hill JC, et al. Effect of stratified care for low back pain in family practice (IMPaCT Back): a prospective population-based sequential comparison. *Ann Fam Med*. 2014;12:102–111.

**38.** Long A, Donelson R, Fung T. Does it matter which exercise? A randomized control trial of exercise for low back pain. *Spine.* 2004;29:2593–2602.

**39.** Cooper NA, Scavo KM, Strickland KJ et al. Prevalence of gluteus medius weakness in people with chronic low back pain compared to healthy controls. *Eur Spine J*. 2016;25:1258–1265.

**40.** Brumagne S, Janssens L, Knapen S et al. Persons with recurrent low back pain exhibit a rigid postural control strategy. *Eur Spine J*. 2008;17:1177–1184.

**41.** Lazar JM, Khanna N, Chesler R, Salciccioli L et al. Swimming and the heart. *Int J Cardiol*. 2013;168:19–26.